VEGETABLE STORAGE

Physiological and Biochemical Effects of Storage Humidity on Sweet Potatoes

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Orange Little Stem and Yellow Jersey sweet potatoes were cured and then stored at 60° F. at 70 to 75, 80 to 85, and 95 to 100% relative humidity. Humidity of storage had relatively little effect on the carotenoid pigments or ascorbic acid content. Carotenoids increased and ascorbic acid decreased at all humidities. Differences in weight may result in a concentration of these constituents and give the illusion of greater amounts at low humidities. Loss of weight was inversely proportional to humidity of storage. Moisture content increased during storage at high humidity and remained relatively constant at medium or low humidities. Decay tended to be less at the highest humidity. Humidities near 95% or above may result in surface discoloration and should not be used.

TEMPERATURE AND HUMIDITY are generally considered the major environmental factors upon which the storage behavior of sweet potatoes depends. Being of tropical origin, sweet potatoes are very susceptible to low-temperature injury and much study has been given to the effects of storage temperatures.

Much less study has been given to effects of storage humidities.

Early workers were of the opinion that high humidity was conducive to decay and therefore undesirable both during curing and after storage (*4*, *12*, *13*). At that time curing was thought to be primarily a "drying-out" process and adequate ventilation, to remove the moisture given off by the roots, was considered necessary. However, Weimer and Harter (*15*) and Artschwager and Starrett (*2*) found that suberization and formation of wound periderm in sweet potatoes occurred much more readily at high humidities than at low. The benefit of curing was then correctly ascribed to healing of harvest wounds and consequent prevention of entrance of decay organisms. A high humidity is now recognized as a primary requisite for rapid curing and should be provided during the curing period.

Manns (*12*), in 1920, reported on the effects of humidity and temperature after curing. After 4 years' study, he concluded that "a humidity of 80% or above is considered dangerous—that is, will produce soft rot." He recommended storage at 55° F. and 60% humidity, and warned against humidities higher than 65%. Whether the higher humidities were the primary cause of the decay he observed may be questioned. Geise (*4*) reported in 1922 that extensive investigational evidence, together with practical experience, showed that 60 to 70% relative humidity at 55° F. gave best results, but presented no data. Lauritzen and Harter (*10*) reported that cut sweet potatoes held at 73.4° F. developed Rhizopus rots most readily at a relative humidity of 75 to 84%. Departures from this optimum, either above or below, decreased the amount of infection by Rhizopus. Lauritzen (*9*) reported that infection of sweet potatoes held at a chilling temperature was, in general, directly proportional to the relative humidity, as long as 100% infection was not reached. Jones and Rosa (*7*), in 1928, stated that the humidity factor in sweet potato storages had not received the attention it deserved. They expressed the opinion that a hygrograph was probably more essential to the management of a storage house than a thermometer.

While recommendations for the storage of sweet potatoes usually include specifications for humidity, most of these are based on general observations rather than well-controlled studies. Humidity recommendations have consequently varied in conformity to the latest observations and information of those making

Table I. Carotene, Total Carotenoid, Ascorbic Acid, and Moisture Contents and Loss in Weight in Sweet Potatoes Stored at Different Humidities, 1953–54

	Carotene[a], Mg./100 G.	Total Carotenoids[a], Mg./100 G.	Ascorbic Acid[a], Mg./100 G.	Moisture Content, %	Loss in Weight, %
Orange Little Stem					
At harvest	5.39	6.48	34.8	74.0	
6-month storage					
High humidity[b] at 60° F.	6.80	7.35	18.5	76.6	16.5
Low humidity[c] at 60° F.	6.36	6.93	17.9	74.4	21.5
Low humidity[c] plus air movement at 60° F.	5.92	6.57	18.2	73.8	22.4
Medium humidity[d] at 55° F.	5.90	6.39	15.4	74.7	18.9
Least significant difference					
1%	0.472	0.462	1.59	0.77	1.49
5%	0.356	0.348	1.20	0.58	1.12
Yellow Jersey					
At harvest	0.199	0.944	25.2	74.2	
6-month storage					
High humidity at 60° F.	0.279	1.006	8.0	75.2	11.3
Low humidity at 60° F.	0.319	1.092	9.3	74.5	14.4
Low humidity plus air movement at 60° F.	0.339	1.107	9.9	73.7	15.5
Medium humidity at 55° F.	0.262	0.903	8.2	74.0	15.1
Least significant difference					
1%	0.057	0.090	1.15	0.85	0.83
5%	0.043	0.068	0.86	0.64	0.63

[a] Harvest weight basis.
[b] 95 to 100% relative humidity.
[c] 70 to 75% relative humidity.
[d] 80 to 85% relative humidity.

Table II. Carotene, Total Carotenoid, Ascorbic Acid, and Moisture Contents and Loss in Weight in Sweet Potatoes Stored at Different Humidities, 1954–55

	Carotene, Mg./100 G.		*Total Carotenoids, Mg./100 G.*		*Ascorbic Acid, Mg./100 G.*			
	Harvest weight basis	*Storage weight basis*	*Harvest weight basis*	*Storage weight basis*	*Harvest weight basis*	*Storage weight basis*	*Moisture Content, %*	*Loss in Weight, %*
Orange Little Stem								
At harvest	7.27		7.99		46.4		74.8	...
11-week storage								
High humidity[a] at 60° F.	7.36	7.95	8.06	8.70	19.4	20.9	76.1	7.3
Medium humidity[b] at 60° F.	7.16	7.92	8.13	9.00	17.4	19.2	75.6	9.7
Low humidity[c] at 60° F.	7.44	8.44	8.24	9.35	19.4	22.0	74.5	11.8
Medium humidity[b] at 55° F.	7.31	7.88	8.08	8.70	18.9	20.3	75.8	7.3
18-week storage								
High humidity at 60° F.	8.12	8.94	9.03	9.95	15.1	16.6	76.8	9.2
Medium humidity at 60° F.	8.20	9.44	9.14	10.52	15.8	18.1	75.9	13.1
Low humidity at 60° F.	8.53	10.17	9.43	11.24	17.9	21.3	75.1	16.2
Medium humidity at 55° F.	6.84	7.64	7.59	8.48	17.3	19.4	76.1	10.4
25-week storage								
High humidity at 60° F.	8.85	10.18	9.60	11.04	13.1	15.0	78.6	13.0
Medium humidity at 60° F.	9.47	11.49	10.10	12.25	13.9	16.9	76.5	17.5
Low humidity at 60° F.	8.16	10.41	9.10	11.61	14.9	19.0	75.6	21.6
Medium humidity at 55° F.	6.80	7.85	7.68	8.87	14.6	16.9	76.8	13.4
Least significant difference								
1%	0.98	1.15	1.04	1.21	2.17	2.40	0.68	1.14
5%	0.74	0.87	0.78	1.01	1.64	1.81	0.51	0.86
Yellow Jersey								
At harvest	0.188		0.708		34.2		7.68	...
13-week storage								
High humidity at 60° F.	0.294	0.319	0.981	1.066	9.5	10.3	77.7	8.1
Medium humidity at 60° F.	0.260	0.285	0.920	1.009	11.2	12.2	76.9	8.9
Low humidity at 60° F.	0.364	0.412	1.081	1.224	10.5	11.9	76.4	11.7
Medium humidity at 55° F.	0.216	0.235	0.870	0.947	12.3	13.4	77.2	8.1
20-week storage								
High humidity at 60° F.	0.331	0.354	1.011	1.080	6.9	7.4	78.2	6.4
Medium humidity at 60° F.	0.320	0.362	0.986	1.113	8.2	9.2	77.2	11.4
Low humidity at 60° F.	0.375	0.437	0.977	1.138	8.5	9.8	76.2	14.1
Medium humidity at 55° F.	0.285	0.321	0.924	1.039	8.0	9.0	76.9	11.0
28-week storage								
High humidity at 60° F.	0.351	0.389	1.010	1.119	7.4	8.2	78.5	9.7
Medium humidity at 60° F.	0.420	0.490	1.030	1.203	6.6	7.7	77.2	14.3
Low humidity at 60° F.	0.390	0.473	1.027	1.246	8.0	9.7	76.4	17.5
Medium humidity at 55° F.	0.303	0.350	0.877	1.011	7.5	8.6	77.5	13.3
Least significant difference								
1%	0.054	0.061	0.086	0.095	1.55	1.62	0.60	0.97
5%	0.041	0.046	0.065	0.072	1.17	1.25	0.45	0.74

[a] 95 to 100% relative humidity.
[b] 80 to 85% relative humidity.
[c] 70 to 75% relative humidity.

the recommendations. Although the importance of humidity has long been recognized, few data showing its effect on the behavior of well-cured sweet potatoes held at a favorable storage temperature have been published. This paper reports results of work done to supply this information.

Materials and Methods

Orange Little Stem and Yellow Jersey varieties were used in these studies. The former is less dry than the latter and is usually referred to as "semidry" or "semimoist." Both were obtained from commercial growers at time of harvest in early October. The Orange Little Stem variety was grown near Severn, Md., and the Yellow Jersey near Swedesboro, N. J. The roots were washed at harvest to remove adhering soil and weighed individually, and the weight in grams of each root was recorded thereon with an indelible pencil; the roots were reweighed at time of analysis. Composite samples of 50 to 75 roots were analyzed at harvest and after storage. The storage samples were cured at 85° F. and 85 to 95% humidity and stored in a room thermostatically controlled at 60° F.

During the first season the roots were stored for approximately 6 months. Two storage humidities were provided within the same room. High humidity (near saturation) was obtained by storing the sweet potatoes over water in a metal container, with heavy blotting paper along the sides and extending down into the water. The roots were covered with moist cheesecloth and above this, with an air space between, was dry cheesecloth. A triple layer of cheesecloth was then drawn over the top of the cabinet. Low humidity (70 to 75% saturation) was provided in the rest of the room. A third treatment consisted of blowing room air (approximately 375 feet per minute) through an air chute within which sweet potatoes, 8 to 10 inches deep, were resting on a wire screen.

During the second season three storage humidities were provided within the room. High humidity (near saturation) was obtained as in the previous season. Medium humidity (80 to 85% saturation) was mechanically controlled within the room. Low humidity (70 to 75% saturation) was provided in a metal container by regulating the speed of a fan blowing over a drierette containing calcium chloride. The relative humidity within this cabinet was determined with an electric hygrometer. The humidities within the cabinets were exceptionally uniform, remaining near saturation (high humidity) and 72% (low humidity). Outside the cabinets the relative humidity usually remained within the 80 to 85% range, with the mean near 82%.

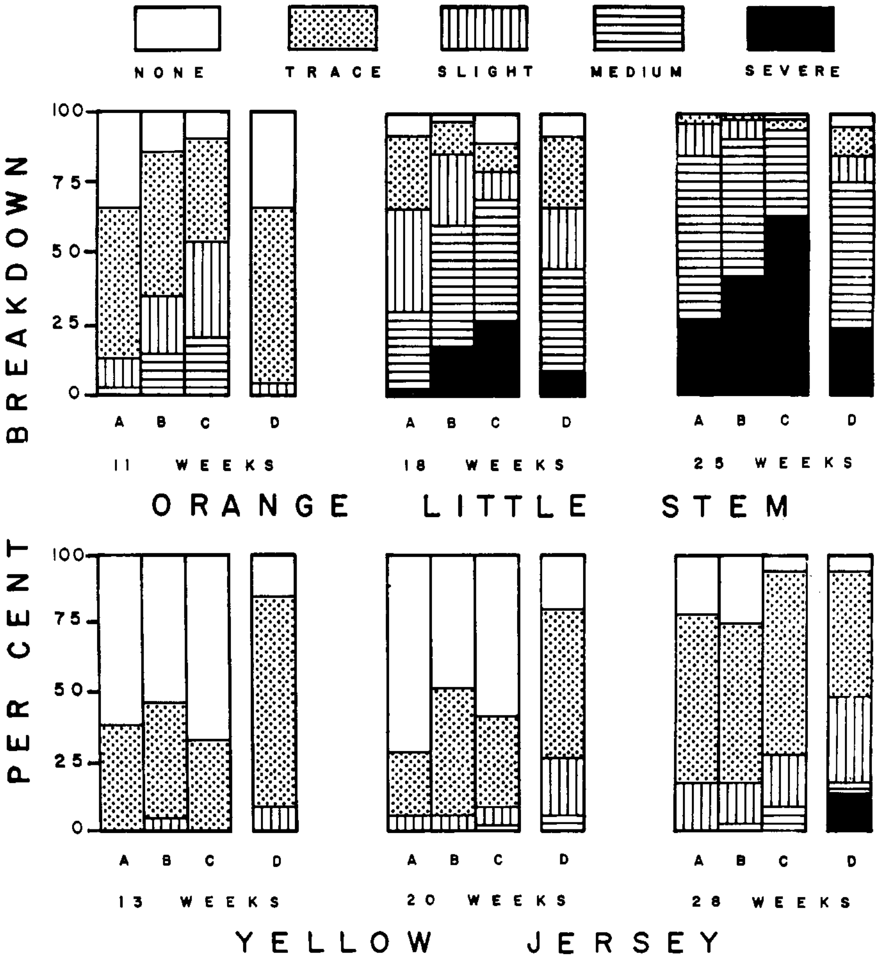
Table III. Effect of Storage Humidity on Decay of Sweet Potatoes

	Orange Little Stem				Yellow Jersey			
	Days in storage	*No. of roots*	*Decay, %*	*Av., %*	*Days in storage*	*No. of roots*	*Decay, %*	*Av., %*
1953–54								
High humidity[a] at 60° F.	186	64	17		182	82	4	
	195	65	17	17.0	...	..	..	4.0
Low humidity[b] at 60° F.	187	67	25		185	84	5	
	199	109	37	31.0	...	..		5.0
Low humidity[b] plus air movement at 60° F.	188	66	27		186	81	7	
	200	62	39	33.0	200	84	7	7.0
Medium humidity[c] at 55° F.	201	66	48		187	84	26	
	202	64	42	45.0	201	85	15	20.5
1954–55								
High humidity at 60° F.	78	52	2		93	54	2	
	128	68	10		136	56	0	
	176	68	13	8.3	193	61	3	1.7
Medium humidity at 60° F.	77	52	2		87	52	4	
	84	55	9		95	54	0	
	127	61	8		135	54	2	
	133	59	15		141	55	0	
	175	62	13	9.4	192	53	9	3.0
Low humidity at 60° F.	79	57	10		92	55	2	
	129	59	15		137	58	7	
	177	58	33	19.3	196	58	0	3.0
Medium humidity at 55° F.	84	58	9		94	55	6	
	132	65	24		140	54	11	
	178	59	32	21.7	197	53	9	8.7

[a] 95 to 100% relative humidity.
[b] 70 to 75% relative humidity.
[c] 80 to 85% relative humidity.

Figure 1. Internal breakdown of sweet potatoes stored at different humidities

A. 95 to 100% relative humidity at 60° F.
B. 80 to 85% relative humidity at 60° F.
C. 70 to 75% relative humidity at 60° F.
D. 80 to 85% relative humidity at 55° F.



For comparison, additional sweet potatoes from the same lots were stored in another room held at 55° F. and 80 to 85% relative humidity each season.

Methods and general procedures for chemical analysis were the same as described previously (*3*). Each sample consisted of 10 replicates of five roots each. The roots were split lengthwise, one half root being used for ascorbic acid and the other for carotenoids and moisture determinations. Ascorbic acid was determined by the method of Loeffler and Ponting (*11*) and the carotenoid pigments by the method of Wall and Kelley (*14*). Both were calculated back to the weight at harvest and reported on the harvest-weight basis. The carotene, total carotenoid, and ascorbic acid contents of each sample as reported are based on duplicate determinations of each of the 10 replicates of five roots each, a total of 50 roots. Moisture contents are based on single determinations of each of the 10 replicates, dried for 24 hours in an electric oven at 158° F., followed by 24 hours at the same temperature under vacuum. Weight loss is based on the difference between weights at harvest and after storage of the individual roots. Roots showing decay were not used for chemical analysis or loss in weight and are included only in total root and percentage decay values. Analysis of variance was used to determine differences required for significance.

For the internal breakdown studies the roots were cut both lengthwise and crosswise at their greatest diameters and scored as follows:

1. None. Flesh normal, no indication of breakdown observed on careful examination.
2. Trace. Beginning breakdown discernible on careful examination.
3. Slight. Breakdown in localized areas evident on casual examination.
4. Medium. Breakdown more widely distributed or with flesh more severely pitted, or both, than in 3.
5. Severe. Breakdown in an advanced stage, with appreciable cavities or with lighter colored cottony areas.

In this classification, "trace" probably would be overlooked commercially and "slight" would attract little attention. Most of the breakdown classed as severe had not reached the stage indicated by Harter and Weimer (*6*, Plate 24, *A* or *B*) or by Artschwager's (*1*) illustrations of internal breakdown.

Results and Discussion

The carotene, total carotenoid, ascorbic acid, and moisture contents and loss of weight of sweet potatoes stored for 6 months at different humidities during the first season are shown in Table I. Similar data for the second season are shown in Table II. Carotene increased during storage at all humidities tested.

Because there were differences in the amount of weight lost at the different humidities, carotene, total carotenoids, and ascorbic acid are presented on the harvest-weight basis to show the actual changes that occurred during storage, regardless of the amount of weight lost. On a storage-weight basis the concentration is relatively higher in lots losing the most weight and consequently more nutritious on a unit-weight basis. This is shown in Table II, where the results are also reported on the storage-weight basis.

During the first season Orange Little Stem sweet potatoes stored at high humidity contained slightly more carotene and total carotenoids (5% level) than those stored at low humidity. They also had a higher moisture content and lost less weight (1% level). Low humidity plus air movement resulted in slightly less carotene, total carotenoids, and moisture content than low humidity alone, but the difference in loss of weight was not enough to be statistically significant. During the second season, carotene and total carotenoids increased during storage, but were not greatly affected by differences in storage humidity. There was no consistent difference in ascorbic acid content at different humidities in either year. Moisture content of the stored sweet potatoes was directly correlated with humidity of storage, and there was a significant increase (1% level) during storage at high and medium humidities and at low humidity after 25 weeks in storage.

During the first season carotene, total carotenoids, and ascorbic acid in the Yellow Jersey variety tended to be slightly higher at low humidity. This same tendency was evident for carotene the second season, but there was no consistent difference in total carotenoids or ascorbic acid. The moisture content increased during storage at high humidity but not at medium or low humidity. Loss of weight in both varieties was inversely proportional to humidity of storage.

Late in the storage season, sweet potatoes that have not succumbed to pathogenic organisms will usually show some internal breakdown (pithy breakdown). Short-keeping varieties show the disorder earlier than long-keeping ones. Unfavorable environmental conditions may hasten its appearance or rate of development. Roots exposed to low temperatures for extended periods before harvest may show internal breakdown at harvest or shortly thereafter. In general, its appearance in sweet potatoes indicates senescence and deterioration of quality in proportion to its severity. With all factors the same except humidity, differences in internal breakdown may serve as a criterion of the effects of storage humidity. During the second season detailed records of internal breakdown were made at each withdrawal (Figure 1).

When internal breakdown was first described, in 1923, Harter, Lauritzen, and Weimer (*5*) stated that "the trouble seems to be associated with conditions of storage. It is more prevalent when the house has been kept fairly dry." Several years later Harter and Weimer (*6*) concluded that the disturbance was in some way correlated with environmental conditions in storage and "probably results from exposure to high temperatures combined with a relatively low humidity." Kimbrough and Bell (*8*) found that exposure to low temperatures may result in severe internal breakdown later. It may well be that any unfavorable environmental condition will result in a shorter storage life of the roots and hasten the development of internal breakdown.

From the results reported here, it appears that low humidity is conducive to the development of internal breakdown, as suggested by Harter, Lauritzen, and Weimer (*5*). This is clearly shown in the shorter keeping Orange Little Stem variety (Figure 1). The effects of temperature appear to vary with variety. At the temperatures used in this study (55° and 60° F. and 80 to 85% relative humidity) the Orange Little Stem consistently showed more internal breakdown at 60° than at 55°, but more roots decayed at 55° (Table III). In the Yellow Jersey there was more internal breakdown, as well as more decay, at 55° than at 60°. In another test, a different lot of Yellow Jersey sweet potatoes was divided into 10 replicate samples of approximately 50 roots each. After curing, five of the replicates were stored for 15 weeks at 55° F. and five at 60° and a relative humidity of 80 to 85% at each temperature. This test also showed more internal breakdown and more decay at 55° than at 60° F. (Figure 2). In an earlier publication (*3*) it was reported that internal breakdown was observed earlier at 50° and 55° than at 70° F., but once under way it developed more rapidly at the higher temperature.

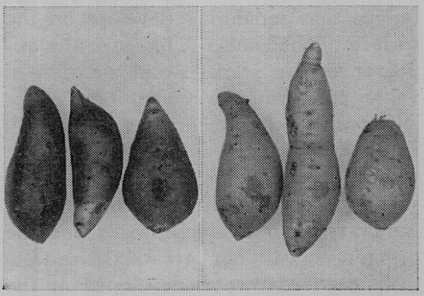


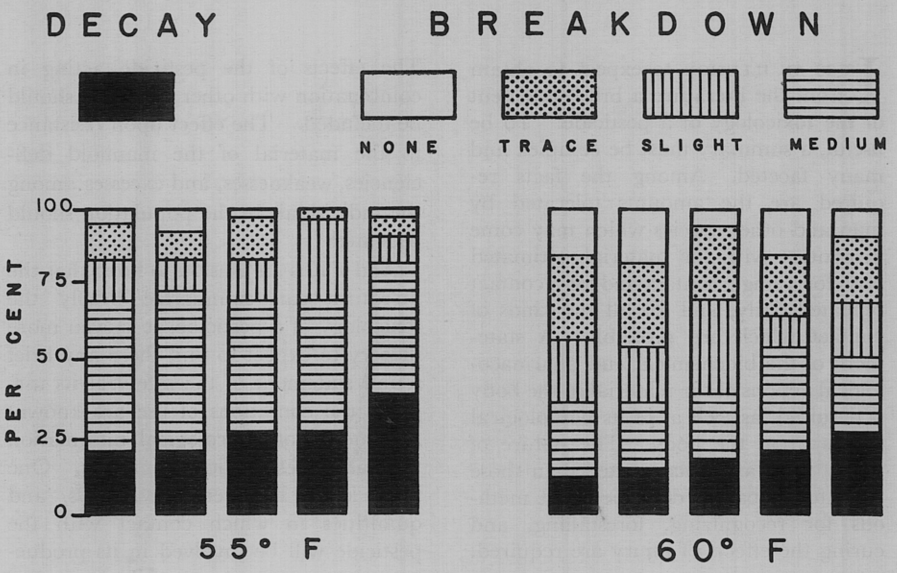
Figure 3. Surface discoloration of sweet potatoes stored at 95 to 100% relative humidity

Left. Discolored
Right. Normal

The decay of sweet potatoes stored at different humidities is shown in Table III. While the results are not conclusive, they show a marked tendency for more decay at the lower humidities. Lauritzen and Harter (*10*) reported that infection of cut sweet potatoes by Rhizopus occurred more readily at a humidity of 75 to 84% than at higher or lower humidities.

Perhaps the most striking visual effect of high humidity is a brownish surface discoloration that occurs in some seasons (Figure 3). In two seasons prior to the studies reported here this discoloration was observed in storage where the humidity was about 95%. During the 1953–54 season little discoloration occurred in experimental lots. During the 1954–55 season the discoloration was

Figure 2. Decay and internal breakdown of replicate lots of Yellow Jersey sweet potatoes stored for 15 weeks at 55° and 60° F. and 80 to 85% relative humidity



evident in both varieties in January and increased in severity as the season advanced. It was most pronounced, becoming almost black, where abrasions or bruising occurred at harvest time. The Yellow Jersey roots shown in Figure 3 were photographed in early June. Also of less importance was a yellow or orange fungus that sometimes develops on the surface of the roots. This gave the appearance of a seepage or exudation of yellow color from the sweet potatoes.

Sprouting was not of major importance in any of the stored lots. During the second season, there appeared to be slightly more sprouting at the highest humidity than at the lowest, but the difference was not great. In a few instances feeder roots developed at the highest humidity.

Conclusions

Humidity of storage had relatively little direct effect on the increase in carotene or the decrease in ascorbic acid during the storage period. It was of major importance in determining loss of weight in sweet potatoes. Low humidity caused excessive loss in weight, and tended to hasten internal breakdown and shorten the storage life. High humidity caused an increase in moisture content of the roots during storage, but no additional decay. A humidity of 95% or above is likely to cause surface discoloration and poor appearance. A relative humidity of 85 to 90% would appear to be optimum for sweet potato storage.

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PESTICIDES LITERATURE

The Literature of Pesticide Toxicology

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There can be no simple, easily summarized statement of the toxicology of a pesticidal material. Both quantitative and qualitative information is required, species differences must be defined, and effects of combination with other materials should be included. Until the conditions of use are known, no amount of toxicological information will allow estimation of safety. Four classes of people require literature on the toxicology of this chemically heterogeneous group: those who develop new materials, those who guard occupational health, those who protect public health, and those who treat persons injured by an excess. Some specific sources of information for each group are suggested.

It is an illusion to expect to obtain from the literature a brief statement of the toxicology of a pesticide. To be useful, a summary must be complex and many faceted. Among the facts required are the amounts tolerated by man and other species which may come in contact with the material, estimated both for a single contact and for a contact repeated daily, and for all the kinds of contact which are probable. A statement of the biochemical and pharmacological actions of the material in the body is required, as well as of its pathological effects upon the body. The nature of injury from amounts greater than those tolerated must be described and methods for recognizing, forestalling, and curing the effects of injury are required. The effects of the pesticide acting in combination with other materials should be included. The effect upon resistance to the material of the manifold deficiencies, weaknesses, and excesses among the individuals in the population should be stated.

And if it is an illusion to hope that the literature can summarize briefly the toxicology of a pesticide, it is even more illusory to expect to find there any brief sound statement of the safety of its use. Until the conditions of use are known, no amount of toxicological information will allow estimation of safety. One must know the frequency, ways, and quantities in which contact with the pesticide will be involved in its production, formulation, transportation, and application, and the frequency, ways, and amounts in which the public will come in contact with materials bearing residues of the pesticides. In order to interpret the toxicological data in terms of safety or hazard, one must compare the amounts of the pesticide in contact and the frequency of contact with the tolerated amounts defined by the toxicologist. One must consider the amounts of other materials which may influence the effects of the pesticide. One must weigh the nature of the effects of excess, the ease of diagnosis of injury, the promptness of recovery from injury, and the availability of an effective antidote to treat accidental poisoning.

The conclusion that a pesticide is safe